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Integrating Solar Heating into an Air Handling Unit to Minimize Energy Consumption

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1. Executive Summary

The purpose of this project was to test a method of integrating solar heating with a small commercial air handling unit (AHU). In order to accomplish this a heat exchanger was placed in the reheat position of the AHU and piped to the solar heating system. This heat exchanger is used to supplement or replace the existing electric reheat. This method was chosen for its ability to utilize solar energy on a more year round basis when compared to a traditional heating system. It allows solar heating to be used for direct heating during winter and for reheating in hot humid summer weather.

Data was taken for seven days without the solar reheat coil (SRC) in place and for eleven days with the SRC in place. For this project two similar days (one with the SRC and one without) were compared and contrasted to determine the feasibility of a solar reheat system. The results have shown that the SRC reduced the electric consumption in the electric reheat coil. There were two main indicators of the energy reduction. First, energy consumption of the electric heater relative to the total energy consumed fell from 33% to 16% with the use of the SRC over a 12-hour period. Secondly, on September 5, 2009 the solar reheat coil saved almost 10 kWh, over 25% of the heater energy required for 24 hour operation.

This project has resulted in a working prototype for solar powered reheat. With a few modifications this system will prove useful in future research. With solar assisted reheat being one of only a few acceptable forms of reheat for ASHRAE 90.1 (2007), interest in this topic will continue to grow and further research will be necessary. Therefore, this project has put Purdue University and the Applied Energy Laboratory (AEL) in a position to be a frontrunner in the up and coming field of solar assisted reheat research.

2. Introduction

The Applied Energy Laboratory (AEL) at Purdue University is located on the fourth floor of Knoy Hall of Technology on the West Lafayette campus and is dedicated to teaching and research related to High Performance Buildings. The lab has approximately 1800 square feet of indoor space and also has additional space for outdoor equipment on the roof of Knoy Hall. The lab can be used for both classroom lectures and teaching labs, with an array of equipment which is used to teach both thermal and fluid science undergraduate lab-based courses.

The AEL at Purdue University focuses on projects relating to energy and building heating ventilating and air conditioning (HVAC) systems. The AEL is set up to mimic the operation of a High Performance Building with the goal of achieving net zero building operation. The lab has also recently begun to emphasize sustainability in its projects. A few examples include the installation of a photovoltaic array and an active loop solar collector array, a project focused on minimizing air conditioning costs while maintaining human thermal comfort, and a project that researched the possibility of combining U.S. and Swiss residential construction practices to minimize energy consumption.

The AEL at Purdue University has continued its focus on sustainability with this project, which integrated an existing solar heating loop with an existing commercial air handling unit (AHU) to assess the potential for energy savings during winter (heating) and summer (reheating). For this project a liquid to air heat exchanger was placed in the existing AHU. The fluid from the active loop solar collectors was run through the coil for supplemental heating purposes.

The glycol exchange system consists of a simple pump circuit which gathers heat from the solar collectors on the roof of Knoy Hall and dissipates the heat to domestic water in a plate and frame heat exchanger in the AEL. Figure 2.1 shows a schematic of the old glycol exchange system. The plate & frame heat exchanger is a key point. The domestic water ran through the heat exchanger to collect the heat. However, this heated domestic water was then run down a drain, wasting the heat along with potable water.

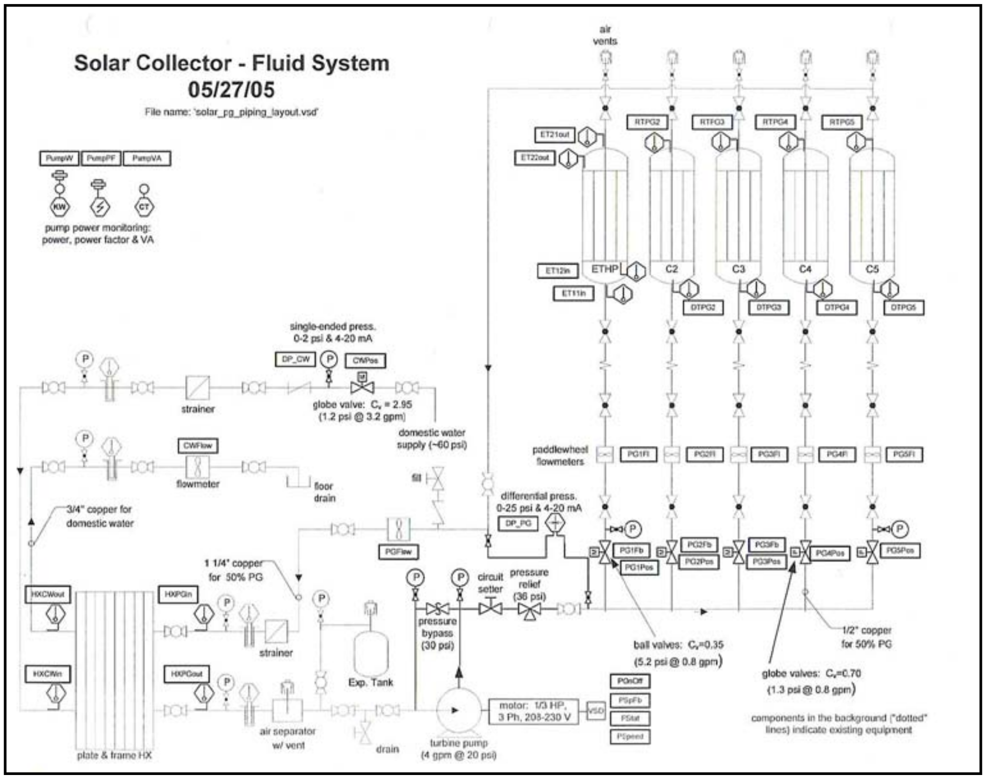

Figure 2.1. Active loop solar system schematic, the solar glycol loop collects solar energy and dissipates it through a heat exchanger

These solar panels vary in design. Figure 2.2 shows the newest panel in the array and is an evacuated heat pipe type. The remaining panels, shown below as Figure 2.3 to Figure 2.6, are slightly older and were built as a test of how panel characteristics affect performance. The panel in Figure 2.3 has a copper back plate with uncoated copper piping. The panels in Figure 2.4 and Figure 2.5 are similar panels both having a black back plate and copper piping that has been painted black; however, the panel in Figure 2.4 has black fins on the piping while the other does not. The panel in Figure 2.6 has an uncoated aluminum back plate and black fined copper piping.

Figure 2.2. Heat Pipe

Figure 2.3. Copper Plate

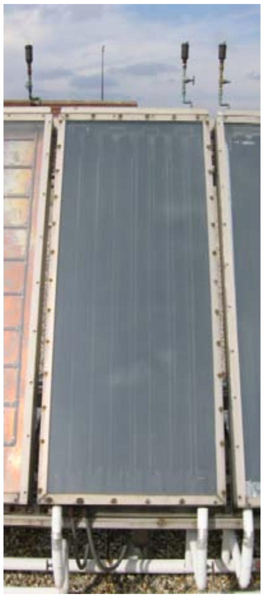

Figure 2.4. Finned Tube Black

Figure 2.5. Flat Black

Figure 2.6. Finned Tube Al

The panels are mounted to improve the performance during the winter season. Purdue University is at latitude of roughly 43 degrees north; however, the panels are mounted south facing at 53 degrees from horizontal. This places the mounting angle at latitude plus 10 degrees. The general rule with solar panels is to mount the panel at latitude minus 10 to 15 degrees to improve summer performance or at latitude plus 10 to 15 degrees to improve winter performance. As a result of mounting the panels at 53 degrees from horizontal the panels on the roof of Knoy Hall will have more direct sunlight in the winter when heating is required.

The AHU in the AEL will be described next as the goal of this project was to integrate the solar system described above with the AHU. The AHU is one of the smallest commercial AHU's that Carrier Corporation makes. As such, the AHU has a maximum air flow rate of 1500 cfm although the current operating flow rate is around 650 cfm. A diagram of the AHU is shown in Figure 2.7, which includes all of the components currently in the AHU. In Figure 2.7, each component is identified with a circle and with a number inside. Number 1 shows the dampers on the return air (RA) and supply air (SA) from the energy recovery ventilator (ERV) as they enter the mixing box. Number 2 is the filter and number 3 is the cooling coil which is supplied by a three ton air cooled chiller in the AEL. Number 4 is the current heating coil which in this AHU is an electric resistance heater. Number 5 is the fan and number 6 is a steam humidifier.

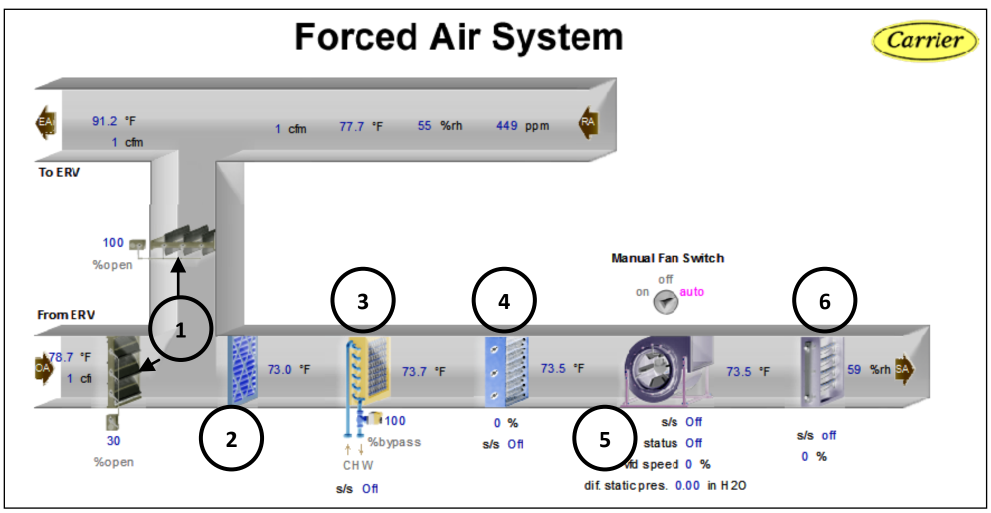

Figure 2.7. [Diagram of AHU in Knoy 425]. (Applied Energy, 2009)

The current air handler configuration uses a significant amount of electric heat. It is used for heating air during the cold winter months and in reheat mode during the summer. In reheat mode, the cooling coil over cools the air for humidity control and the electric heating coil brings the air back to an acceptable temperature before the air enters the controlled zone.

Figure 2.7 shows that an ERV that is coupled to the air handler. The ERV, shown in Figure 2.8, is a latent wheel type. The latent wheel allows this ERV to exchange both heat and humidity between the exhaust air (EA) and ERV SA streams. As such the ERV lowers heating and humidification loads in the winter while decreasing cooling and dehumidification loads in the summer.

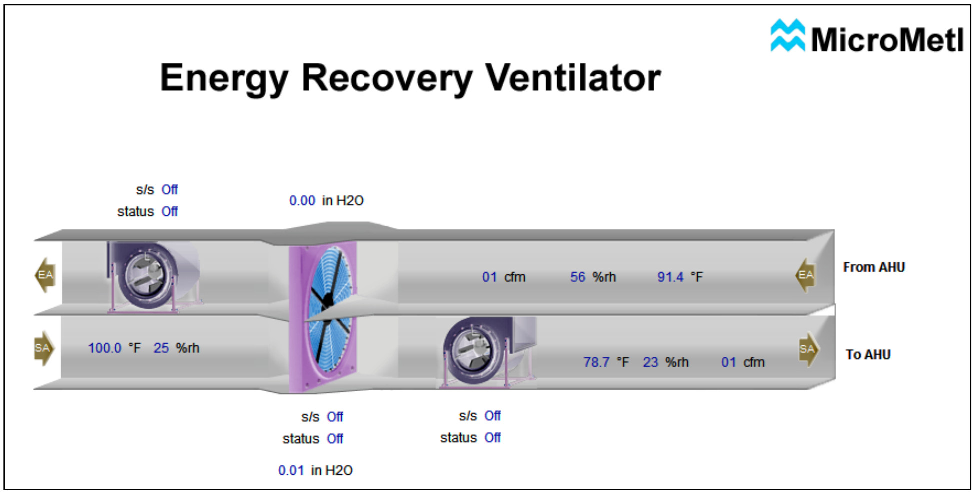

Figure 2.8. [Diagram of ERV on roof of Knoy]. (Applied Energy, 2009)

The AHU discussed above is used to condition an interior chamber. The test chamber is a converted industrial freezer. The chamber is well insulated and set up as a single zone. This chamber is relatively small with internal dimensions of 13’ x 7’ with a 9’ ceiling.

3. Statement of the Problem

The AEL currently has an AHU and a solar array that both waste energy that could be put to a useful purpose. Through individual operation the glycol exchange solar system is wasting the heat gathered along with potable water. The AHU uses an electrical heater, considered to be an inefficient means of heating. Thus, a means of integrating the two systems could reduce energy and water consumption in the AEL.

4. Significance of the Problem

Current economic conditions and federal initiatives combine to create a need for the integration of renewable energy systems into buildings. Currently over 40% of the primary energy and 70% of the electricity in the United States is consumed in buildings (Torcellini, Judkoff, Crawley & Drury, 2004). One of the methods suggested to reduce the energy consumption in buildings is to make net zero energy buildings which create as much energy as they consume. The U.S. Department of Energy (DOE) introduced the Commercial Building Initiative (CBI) with the goal of all new construction commercial buildings being net zero by 2030 and all existing buildings be net zero by 2050 (Jeffrey Harris, public presentation, April 16, 2008). With a large portion of the energy in the United States being consumed in buildings and coupled with the energy initiatives and high energy costs, a cost effective method of integrating renewable energies into current buildings is needed.

5. Statement of the Purpose

The purpose of this project was to demonstrate a method of integrating solar energy into a small commercial single zone air handler with reheat. The goal was accomplished through the installation of a liquid-to-air heat exchanger inside of the AHU. The working fluid from the active loop solar system was run through the heat exchanger inside of the AHU provided supplemental heating used in both heating and reheating modes of operation.

6. Definitions

The terms that are used for this project fall within normal technical nomenclature. There is not a lot of industry specific terminology to explain. However, there are quite a few uncommon abbreviations. The following list includes the abbreviations used in this proposal.

Heating, ventilating and air conditioning, HVAC - Air handling systems designed for temperature, humidity, odor control and air quality. (Burton, 2006)

Air handling unit, AHU – A central unit used to cool or heat air that is then distributed to one or a group of rooms that make up a zone. (Pita, 2002)

Energy recovery ventilator, ERV - a type of mechanical equipment that pre-conditions incoming outdoor air through heat and in some cases humidity transfer between the incoming outdoor air and the exiting relief air from a building.

Return air, RA - Air returned from a conditioned space to the HVAC system. (Burton, 2006)

Supply air, SA - Air supplied to a conditioned space from the HVAC system. (Burton, 2006)

Outdoor air, OA - "Fresh" air mixed with return air (RA) to dilute contaminants in the supply air (SA). (Burton, 2006)

Exhaust air, EA - Air exhausted to the outdoor environment from the HVAC system. (Burton, 2006)

Relative Humidity, RH – The ratio of the water vapor (by weight) in air to the water vapor in saturated air at the same temperature and pressure. (Janis & Tao, 2008)

Percent of outside air, %OA - Percent of total air supply from the HVAC system that came from outside.

7. Literature Review

The purpose of this literature review was to evaluate applications of solar energy in buildings. The feasibility of utilizing each application in the AEL was also reviewed. Finally a conclusion was reached in which the most feasible application of solar energy in the AEL was chosen for this project. The technologies were reviewed in two large groups and broken down into categories inside each group. The two groups that were reviewed are solar cooling technologies and solar heating technologies.

7.1. Solar Cooling Technologies

Although it seems counterintuitive at first, there are many methods and technologies for utilizing solar energy in HVAC systems for cooling. Since cooling is typically required when the most solar energy is available solar cooling technologies seem to be an attractive option. Hwang, Radermacher, Alili, and Kubo (2008) present many methods of utilizing solar energy for cooling. As shown in Figure 7.1.1 Hwang et al. (2008) solar cooling technologies are divided into three categories. Most of these solar cooling technologies shown in Figure 7.1.1 will be discussed as well as the feasibility of utilizing each in the AEL. However, since not all of the listed technologies will be discussed, the article by Hwang et al. (2008) would be a great resource for any further questions on these technologies.

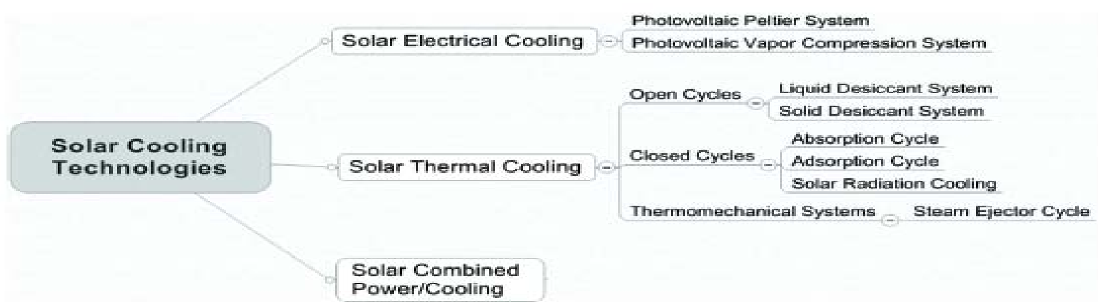

Figure 7.1.1. Solar cooling technologies overview. (Hwang, Radermacher, Alili, & Kubo, 2008)

Solar Electrical Cooling

The first of the three categories described by Hwang et al. (2008) is “Solar Electrical Cooling”. Solar electrical cooling is based on the use of photovoltaic panels which are used to convert light energy into electricity. As shown in Figure 7.1.1 the direct current (DC) electricity generated is supplied to either a Peltier cooling system or a more standard vapor compression system like a traditional air conditioning unit.

Solar electrical cooling could be an option for the AEL as a PV array and electrically driven chiller are both utilized in the laboratory. The PV array could be used to power the chiller; however, the energy is already being utilized in the lab and simply switching the use of the electricity would not be saving any energy as the currently supported system would then need to be supported with grid power. Additionally, the PV array is not tied into the electrical grid; therefore, the chiller would only be able to run when there was sufficient solar energy available or stored in the batteries. Finally, the existing PV array is too small to power the chiller already used in the laboratory.

Solar Thermal Cooling

The second category presented by Hwang et al. (2008), "Solar Thermal Cooling" contains a vast number of technologies; however, only sorption cycles in particular absorption will be evaluated. Figure 7.1.1 shows the sorption cycles under sub category "Closed Cycles", which primarily consist of absorption (liquid sorption) and adsorption (solid sorption) cycles. Both cycles are similar to a vapor compression cycle; however, they use a primary heat source and a sorption material to drive the cycle as opposed to a compressor.

The AEL has previously investigated the feasibility of an indirect fired absorption chiller utilizing heat form the solar heating array. However, there are a few issues with utilizing a sorption process chiller in the AEL. First, the sorption processes typically have very low COPs. They also require a higher temperature heat input than the current solar heating system in AEL can provide. According to Hwang et al. (2008) a single effect absorption chiller would require a heat input at 85 degrees Celsius and would operate with a COP of only 0.7. There is also the practical issue of obtaining an indirect fired absorption chiller. Currently, there are not many commercial products available and the few that are available are much too large for the AEL. Lastly, the AEL does not require year round cooling; this means that for a large portion of the year the system would not be utilized.

Solar Combined Power/Cooling

The third and final category presented by Hwang et al. (2008) is the "Solar Combined Power/Cooling" cycles. This cycle combines the Rankine and absorption cycles to improve overall efficiency. The cycle is similar to a typical solar absorption cycle; however, in place of the metering device typically used to drop the temperature and pressure of the working fluid is a gas turbine. This gas turbine completes the task of the metering device while generating mechanical work which can be used to generate electricity.

The feasibility of utilizing a "Solar Combined Power/Cooling" has similar issues to that of an absorption chiller. Just like with the absorption chiller this technology is not commercially available in a size that would be feasible for the AEL. While the power generation aspect of the combined power and cooling systems does raise the COP a little, the COP of the cycle is still roughly the same as a typical absorption cycle. This system also produces cooling when it is not required in the AEL which would not be utilized and therefore the only useful output of the system for a large portion of the year would be very little electricity.

7.2. Solar Heating Technologies

Many solar heating technologies exist, since most solar panels convert solar energy directly into heat. This section will review a few solar heating technologies; passive technologies will not be reviewed or considered for this project. In particular solar assisted heat pumps, solar air heaters and solar fluid heaters will be discussed.

Solar Assisted Heat Pump

In order to circumvent the low COPs of the solar cooling technologies, Kuang, Wang, and Yu (2003) and Heppelmann et al. (2006) proposed the use of heat pumps, as they tend to have higher COPs than the solar cooling technologies presented by Hwang et al. (2008) and are more reliable sources of cooling. However, while operating in cooling mode, the heat pump does not utilize solar energy. A solar assisted heat pump is similar to an ordinary water source heat pump except the evaporator coil is supplied with solar heat in order to circumvent the low COPs associated with operating a heat pump in heating mode with an extremely low evaporator temperature. Improving the COP when operating in heating mode is the primary reason for assisting a heat pump with solar energy. This is accomplished by coupling a fluid filled active loop solar system, typically with a storage tank, with the evaporator coil. This is accomplished by ensuring the evaporator (the coil that harvests ambient heat energy) temperature is as high as possible to maintain a high COP. Heppelmann et al. (2006), shows a drastic decline in COP as evaporator temperature decreases.

The main issue with utilizing a solar powered heat pump in the AEL is the system only utilizes solar energy on cold days when the evaporator temperature is low; this means that for a majority of the year the solar energy will not be utilized. While in the summer this system would be practically the same as the current electric chiller already in place in the AEL making the solar powered heat pump a redundant system. As mentioned the project is looking to maximize the use of the solar energy available over the course of an entire year.

Solar Air Heaters

The second heating option to be discussed is solar air heaters, in this case used for preheating incoming OA. Yoshie, Satake, Mochida, Kato and Yoshino (2006) and SolarWall both use solar energy to preheat incoming OA. Yoshie et al. (2006) integrated an air exchange solar collector into the balcony of condominiums. The solar collector used by Yoshie et al. (2006) was simply a flat plate solar collector, similar to the collectors in the AEL, placed where a handrail would traditionally be placed; this solar panel preheated incoming OA before it entered the condominium. The SolarWall system, seen in Figure 7.2.1, is a commercially available system that is similar to the system used by Yoshie et al. (2006); however, it is a sheet metal structure that attaches to the building façade. SolarWall uses a steel façade with an air gap to heat air as it flows between the façade and the building toward the air intake of the building.

Figure 7.2.1. SolarWall on warehouse. (SolarWall, 2008)

Preheating air with solar air heaters is a feasible option for the AEL. As mentioned previously, the AEL does have three of these panels already in place and they could be utilized to preheat incoming OA when the outdoor temperature is low. However, as with many of the technologies reviewed thus far, this technology does not lend itself to year round utilization since it is only useful when the OA temperature is low enough to require preheating of the air. Additionally, the AEL already has an energy recovery ventilator in place which does a large majority of the preheating required for the system in the AEL, thus making preheating air a little less attractive of an option, yet, still feasible as there are few other options for the air panels.

Solar Fluid Heaters

The last option for solar heating is the fluid filled active loop systems. Solar Panels Plus currently offers a commercially available solar energy system that is similar in size and scope to what is being proposed for this project. Figure 7.2.2 shows the Panels Plus system, which utilizes solar energy to provide a heated fluid to a heat exchanger inside existing air ducts. The system collects solar energy which is then stored in a tank until it is needed in the ducts to provide heat to the conditioned space.

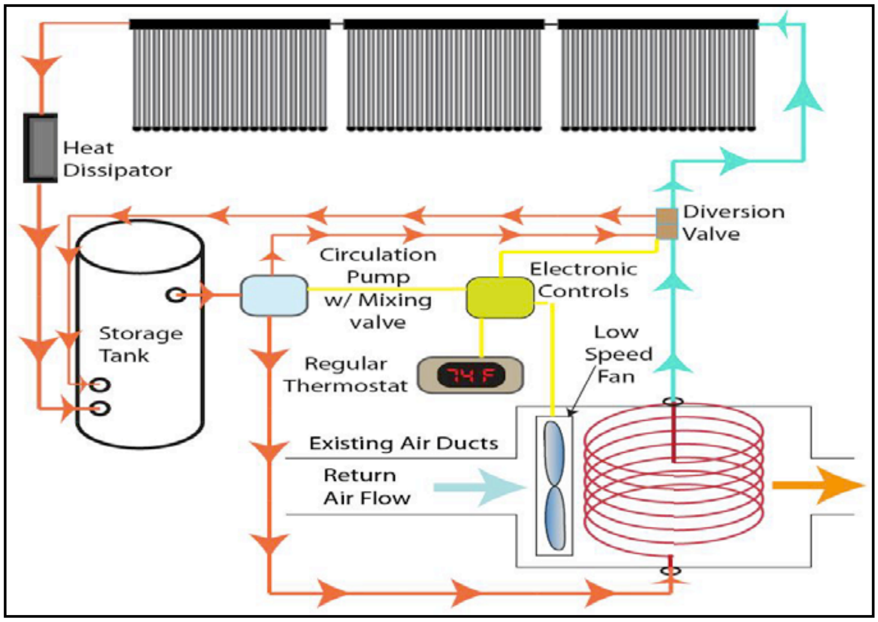

Figure 7.2.2. Solar heating integrated into existing air ducts. (Solar heating, 2008)

Solar fluid heaters are also an efficient method of heating, which would be feasible in the AEL. Like the solar air heaters fluid filled active loops systems are also currently commercially available. The Solar Panels Plus system or a similar one could be easily implemented in the AEL. If the heated fluid is used in a heating coil in the reheat position of the AHU in the AEL, it could be utilized closer to year round than the other systems reviewed.

7.3. Conclusions

Many different technologies and methods of utilizing solar energy in HVAC equipment have been reviewed. As presented in the feasibility section, the solar cooling technologies were determined to not be ideal for this project due to high first cost, low COPs and limited use (only when cooling is required). One of the solar heating technologies presented was the solar assisted heat pump. As discussed, this system also only uses solar energy for a limited portion of the year in a four season climate. This limited use of solar energy along with the high first cost of a heat pump eliminated the solar assisted heat pump from consideration for this project.

The remaining two technologies, solar air and fluid heaters, are both efficient and panels that could be used with each system are currently installed in the AEL. However, the solar air heaters have the same problem as the other technologies presented; they can only be used when heating is required during the day which is roughly a quarter of the year. The AEL also has an ERV installed as discussed in the introduction. This ERV already preheats incoming outdoor air as such solar air heaters are not the most feasible option.

A system very similar to the Solar Panels Plus system was seen as the most feasible option for the AEL. With a traditional AHU with reheat the system proposed would be able to supplement the electric heater when heating is required and would also be able to supplement the electric heater when reheat is required after dehumidification. This mode of operation allows for a higher utilization of the solar energy collected throughout the year and was seen as the best option.

8. Delimitations

A few of the delimitations of the project were utilizing the current solar array and taking a minimalist approach to the project. First, since the current solar array was used the array was not scaled to the AHU used in this project. The mismatch in size between these two systems limited the overall performance. Second, a minimalist approach was be taken on this project which limited the sophistication of the system that was installed. For example, no thermal storage was used, which could have increased the functionality of the system. However, it would have added another degree of difficulty and expense that was not desired in what was to be an easy retrofit design.

9. Limitations

The major limitations of this study was be the possibility of: cloud cover, inclement temperatures and humidity during the study. First, cloud cover had a large effect on the amount of energy reduction that was seen from the solar heater. Second, in order for the energy reduction in reheat mode to be tested the temperature and humidity both had to be high enough to require dehumidification and reheat. If the temperature and humidity did not get high enough and reheat was not required then it was not possible to gather data on the energy reduction offered by the solar array. There was also the limitation of varying efficiencies of the solar panels used. The panels greatly influenced the overall efficiency of the cycle and each of the different panel designs had varying efficiencies.

10. Procedures

Table 10.1 shows the timeline for completing this project. The left column shows the major tasks. Each task will be discussed in more detail later in this report. The top row shows that this project was completed over the last year and a half. Work started in January 2009 and was completed in April 2010. The shaded boxes correspond to the time that was spent on each of the components of the project.

Table 10.1. Project Timeline

	Jan 09	Feb 09	Mar 09	Apr 09	May 09	Jun 09	Jul 09	Aug 09	Sep 09	Oct 09	Nov 09	Dec 09	Jan 10	Feb 10
11.1 Energy Analysis														
11.2 Mechanical														
11.3 Controls														
11.4 Test Protocol														
11.5 Data														

10.1. Energy Analysis

Table 10.1.1 summarizes both the quantity and value of energy from the solar heating system. The value for insolation reflects the total amount of incident energy that hits the solar heating panels over the course of a typical year. The value of energy absorbed shows the amount of energy that should be collected by the system in the AEL over a typical year. The electricity cost was obtained from the Energy

Information Administration (EIA) for a commercial customer in 2008. Lastly the savings shows the cost savings of utilizing all of the energy collected to replace electric heating.

Table 10.1.1 shows that the maximum annual savings that could be realized by the system in the AEL is about $430 per year. The annual savings place an upper limit on the amount of money a building owner should be willing to invest to retrofit a building for solar energy. To achieve a 5-year payback, the installed cost should not exceed $2,150. It is unlikely that a solar system could be installed for this amount of money. However, the system could become more financially attractive if it were on small part of a larger solar installation. For example, a larger solar heating system could also be used for domestic hot water or for process heat. Additionally, as energy prices continue to increase, the viability of solar energy will continue to increase.

Table 10.1.1. Preliminary Energy and Cost Savings Calculations

Solar Heating System	
Insolation (kWh/yr)	11900
Energy Absorbed (kWh/yr)	5350
Electricity Cost ($/kWh)	0.0807
Savings ($/yr)	430

Figure 10.1.1 shows the total insolation on the solar heating system on the roof of the AEL by month for a typical year. In Figure 10.1.1 the vertical axis reflects the monthly insolation in kilowatt-hours. The horizontal axis shows months of the year. Figure 10.1.1 shows that the most solar energy is available from June to October, which is the time of year when cooling and dehumidification are most heavily required in Indiana. Lesser amounts of energy are available during the heating season of roughly November to March.

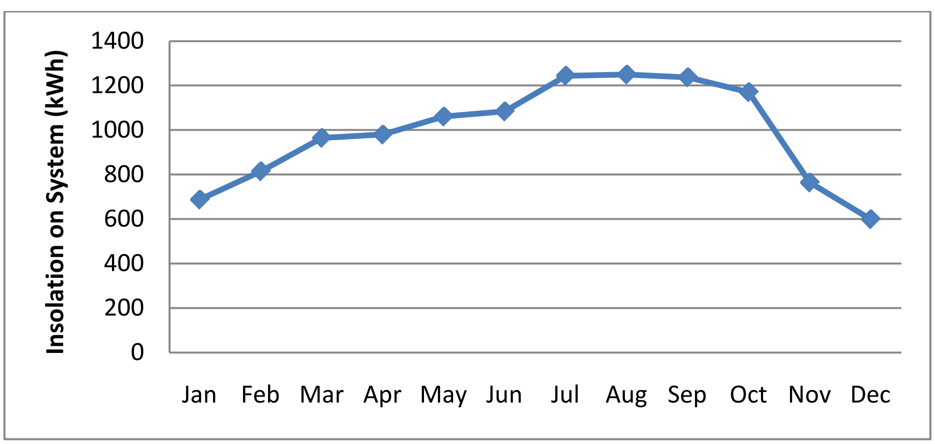

Figure 10.1.1. Insolation on Solar Heating System over a Typical Year

Figure 10.1.1 also implies that a solar energy system will be more economically viable if it is able to use solar energy all months of the year. If the system is only used for heating, say from October to March, the energy available during the peak months from April to September is wasted. The most energy is available during the cooling and dehumidifying season and it needs to be put to good use. As such, the design for this project needed to use the solar heat while the AHU is operating in dehumidification mode.

Figure 10.1.2 is a schematic view of the mechanical systems in the AEL after the completion of this project. The main components of the mechanical systems are outlined with dashed boxes and labeled. First the ERV, which contains a heat recovery wheel, is shown on the left. The larger dashed box in the middle outlines the AHU. The small dashed box inside the AHU contains the SRC which was added for this project. Lastly, the dashed box on the right hand side of Figure 10.1.2 represents the zone served by the AHU.

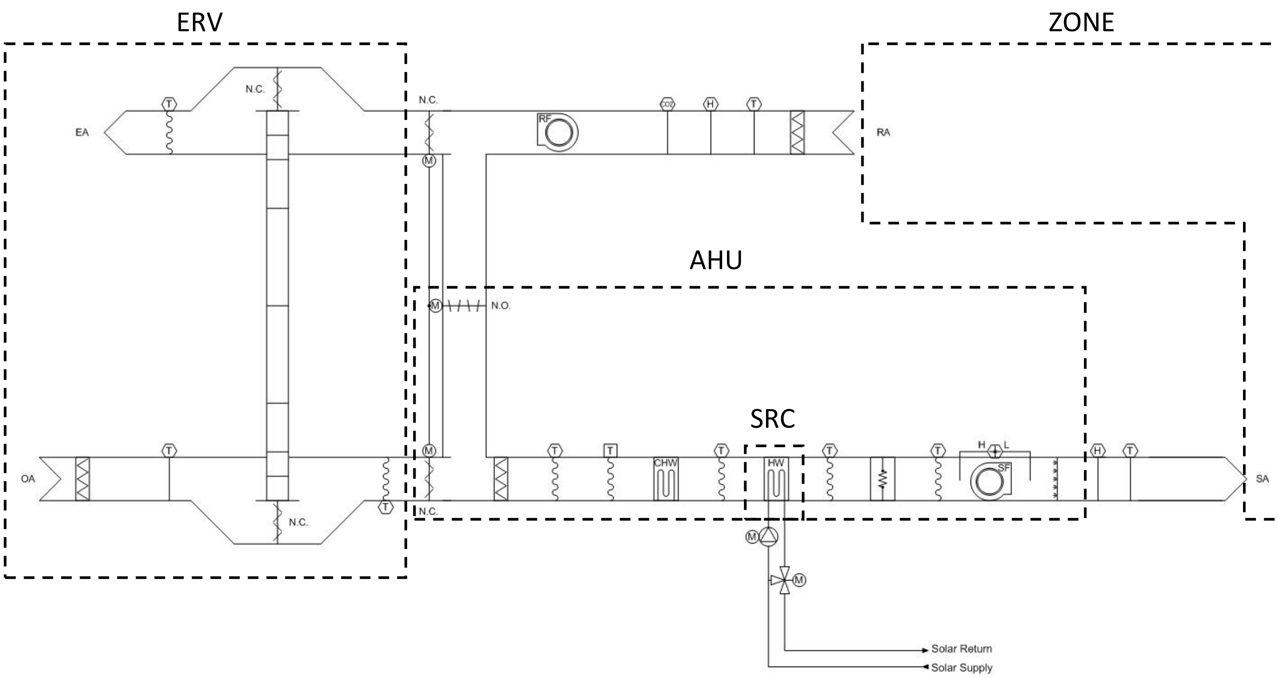

Figure 10.1.2. Schematic view of AHU after the completion of project

In Figure 10.1.2 incoming outdoor air (OA) enters in the lower left at the OA label. The incoming OA crosses the ERV heat recovery wheel before mixing with the recirculated air. The mixed air then flows through the AHU where it is conditioned. The SA is then sent to the zone at the SA label on the lower right side. After conditioning the zone the air returns at the return air (RA) label on the top right side. The air then splits just after the return fan. Some of the air is recirculated and follows the same path as already discussed. The remaining air passes over the heat recovery wheel in the ERV and is then exhausted at the EA label on the top left side of the figure.

The design for this project needed to utilize as much of the solar energy as possible. Therefore, the system needed to use the solar energy during the heating season, but also utilize the large amounts of energy available during the cooling and dehumidification season. With these constraints, the design that worked the best with the system in the AEL was one that utilized a hot water heat exchanger in the reheat position that used the solar heated hot water.

Figure 10.1.2 shows the SRC in a dashed box labeled SRC inside the reheat type AHU in the AEL. By placing the coil in the reheat position this design allowed the SRC to be utilized for heating like most similar systems. Additionally, this position of the SRC also allowed the coil to be utilized for reheat during dehumidification, which Figure 10.1.1 shows is when the most solar energy is available. This allows SRC to supplement to electric heating closer to year-round.

10.2. Mechanical Design

This project addressed four major aspects of the mechanical design. The first was the sizing and acquisition of the heating coil itself. After the coil was designed, a set of brackets to hold it in place was designed and fabricated. The third issue was determining how to connect the SRC to the solar heating system. The last aspect of this project was insulating this system, especially since it does not have a tank and any heat loss from the piping would have a large effect on the efficiency of the system. Each of these aspects will be discussed individually in this section.

Heat Exchanger Sizing

The first stage of the mechanical design was to size the heating coil that would be placed in the air handler. The first constraint was that the coil had to physically fit in the small space available between the cooling coil and electric reheat coil as seen in Figure 10.2.1. The coil also needed to be designed for both a worst case heating and cooling day. Weather data for Lafayette, IN was used for both the worst case heating design day as well as the worst case cooling design day. The following section reviews the design for both conditions.

Figure 10.2.1. Space limitations for SRC.

The design for both heating and cooling/dehumidification conditions had some similarities. First the coil was designed for a constant zone load at the AHU's typical operating airflow of 650 CFM. The design load was a 1000 watt load in the zone for both conditions. In the summer (cooling/dehumidification) there was a 1000 watt heating gain to simulate heat gains from transmission, people and equipment. In the winter (heating), there was a 1000 watt heat loss on the zone to simulate transmission heat loss.

Figure 10.2.2 illustrates the design temperatures that were used for the design when the AHU is heating (winter). There are four key temperatures that influence the design. The entering OA temperature in Figure 10.2.2 is -5 ˚F, which is the 95% worst case design heating day for Lafayette, IN. The temperature in the zone corresponds to the return air temperature (RAT) which is programmed to be 70˚F for heating (winter) and is typical for indoor comfort. The supply air temperature (SAT) from the ERV was calculated to be 64 ˚F on a design day. The SAT computation was based on an ERV effectiveness of 65%. Finally, the SAT to the zone, assuming a zone load of 1000 watts, was determined to be 75 ˚F.

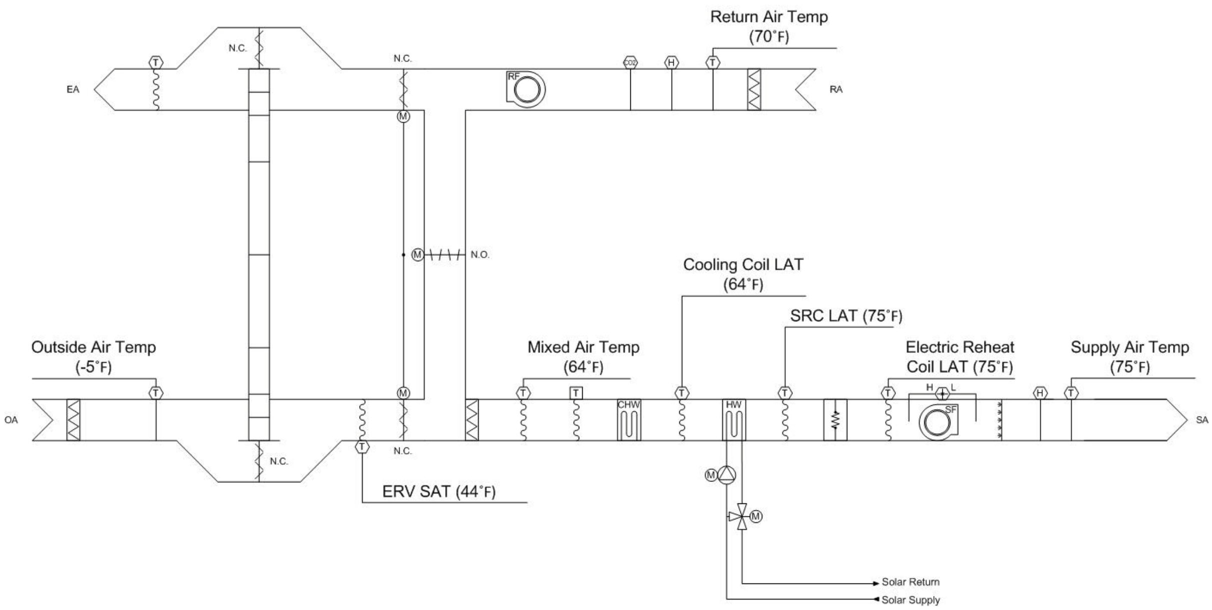

Figure 10.2.2. SRC heating design conditions in AHU

Figure 10.2.3 illustrates the design temperatures that were used when the AHU is dehumidifying. As with the heating design, in order to better understand Figure 10.2.3, a discussion of the each temperature and how each was determined is needed. First, unlike with the heating design, a design OA temperature was not required. The reason the OA temperature was not required was that the solar heating system only runs when dehumidification is required. As such the AHU controls the return relative humidity (RH) to 55%. Since the zone has a sensible heat ratio of roughly 100%, this results in a cooling coil leaving air temperature (LAT) of 55˚F. Once again since the heater is being utilized the RAT is controlled to 70˚F. With a known zone cooling load of 1000 watts, the SAT required to carry the load was calculated to be 65˚F.

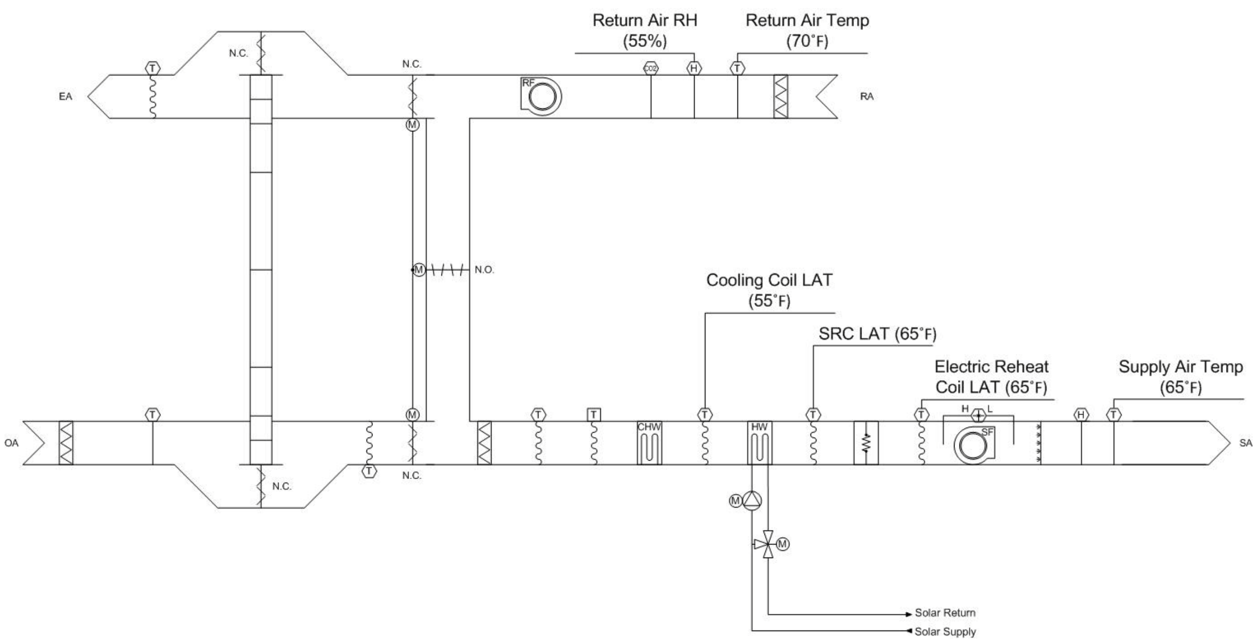

Figure 10.2.3. SRC dehumidification design conditions in AHU

Moving from the design criteria to a viable coil was completed by personnel from Trane. Using the information Figures 10.2.2 and 10.2.3 as well as the size constraints, Trane designed a custom coil for the application. After a review of the coil specifications, which can be found in Appendix 15.1, Trane had the coil manufactured and donated to Purdue for use with this project.

Heat Exchanger Bracket

With the heat exchanger chosen, the next challenge was mounting the heat exchanger inside the AHU. The bracket needed to hold the coil close to the top of the AHU which is where the piping would be connected. The bracket also needed to incorporate an air dam to limit the flow that could bypass the heat exchanger since the coil does not fill the entire flow area of the AHU. A picture of the bracket with the coil mounted on it can be seen in Figure 10.2.4. The assembly pictured in Figure 10.2.4 was placed in the AHU and not mounted down as the weight and piping hold the coil in place.

Figure 10.2.4. SRC mounted on bracket before installation

System Connections/Piping

With the heat exchanger in place in the AHU, the next step was to determine how to connect it to the solar heating system. There were three issues that needed to be considered when physically connecting the two systems; the first was determining where to connect into the solar heating system. Next, the type of piping needed to be determined. Finally, the method and components for measuring and controlling the flow into the coil was considered.

Figure 10.2.5 is a schematic view of the solar heating system after the completion of this project. The connections were made to bypass the heat exchanger that was previously used to remove heat from the solar system. The labels "Solar Inlet" and "Solar Outlet", located in the dashed box, show the locations where the piping for the solar heating coil was connected. The connection was made by utilizing the quick connect fittings previously in place and using valves to isolate the older plate and frame heat exchanger, effectively forcing the fluid to the new heat exchanger.

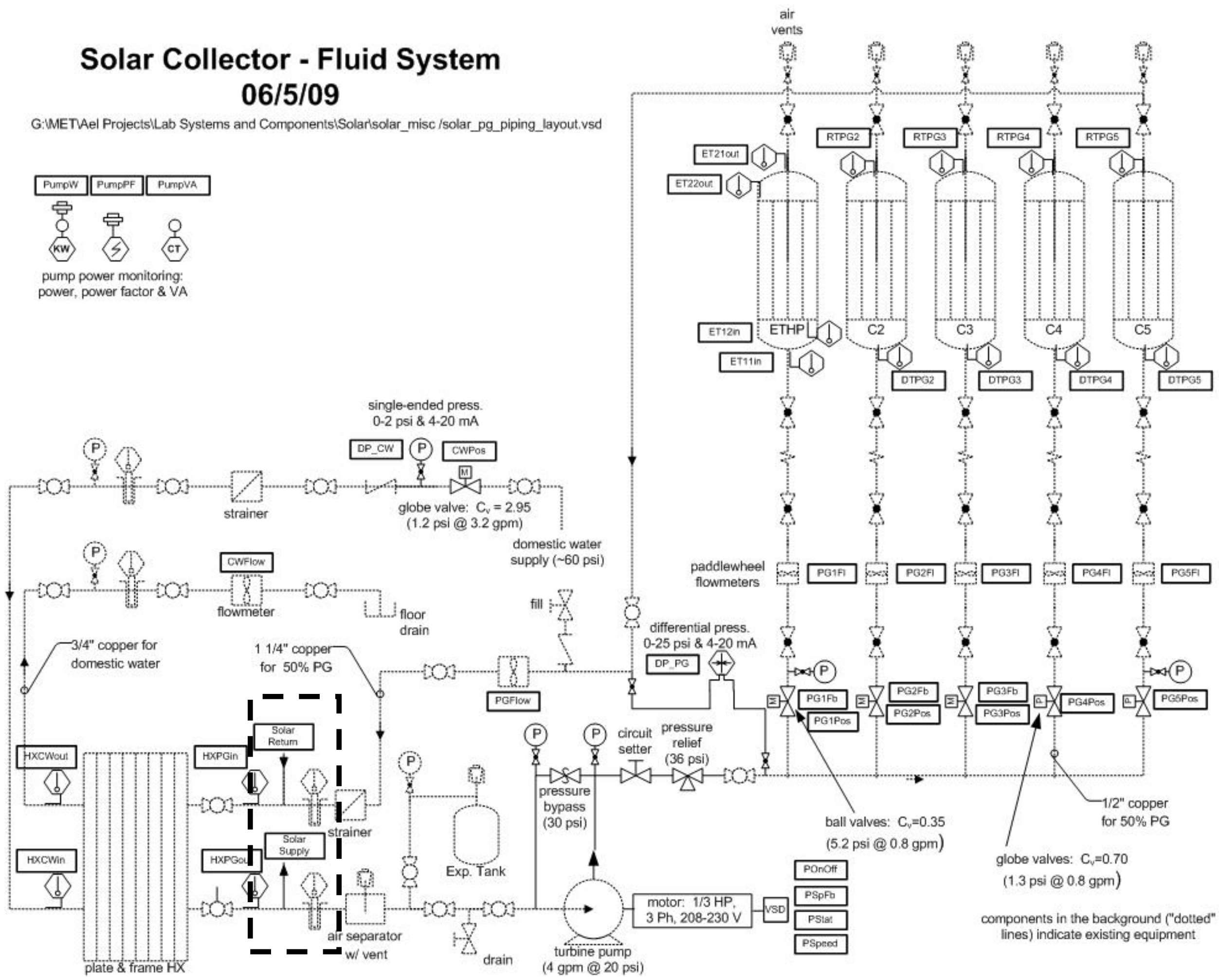

Figure 10.2.5. Solar Heating System Piping after Completion of Project

Two different types of piping were considered for this project. Copper pipe was considered because the current solar heating system is piped using copper; however, PEX was also considered. PEX is an abbreviation for cross-linked polyethylene that is commonly used in residential construction. PEX is flexible so it is easy to route and the fittings are installed by using an expander tool and then simply placing the fitting inside of the tubing before it contracts. Copper, on the other hand, takes much longer because each section of pipe needs to be cut to length and all of the fittings and pipe need to be fitted and brazed together. PEX piping was ultimately chosen for this project mainly for its ease of installation.

The final step was determining what control components and sensors needed to be integrated into the piping system. It was determined that two control components would need to be integrated into the piping design. Figure 10.2.6 shows a coil bypass valve that was installed to control the flow through the coil. This valve would modulate flow though the coil as it is need for heating and bypass the flow when heating is not required. Since the solar system needs a continuous flow, this method allows the solar system to flow when the coil does not need heat.

Figure 10.2.6. Controls Equipment

Figure 10.2.6 also shows a flow meter that was integrated into the piping. This flow meter was needed to determine the flow going through the coil. As mentioned, this system used a bypass valve so not all of the flow from the solar system goes through the coil. As such, a method of measuring the flow going through the coil was required. Figure 10.2.6 shows how the flow meter and control valve were integrated into the piping system. In this image the piping is not completed; however, in this early stage it is easier to see the components. The need for and control of these components will be discussed in more detail in the controls design section later.

Insulation

The last consideration for the mechanical design of this project was how to insulate the pipes to reduce the temperature loss through the PEX tubing. It was determined that conventional pipe insulation would be used and that the highest R-value insulation that was practical and accessible would be selected. There were two different types of insulation that were readily available for this project and both had the same insulation value and were roughly the same price; however, one was made of foam and the other of rubber. The decision was made to use the rubber insulation because it is more durable and should last longer in the AEL.

10.3. Controls Design

The controls design of this project had four main components. The first was determining a sequence of operations for the system. The second was enabling communication between both the AHU controller and the solar system controller. The third was determining the additional hardware and wiring that this project would require. Lastly, the design of the software controls included software programming for both controllers.

Sequence of Operations

The first component of the controls design was determining the sequence of operations. The sequence of operations, shown below, was been broken down into two sections. The two sections labeled “AHU Controller (ALC)” and “Solar Heating System Controller (KMC)” each pertains to a different controller with different control software. As such, the sequence below the AHU controller heading was added to the control code for the AHU while the sequence under the solar heating system controller heading was added to the control code for the solar heating system.

The sequence of operation for the AHU controller is shown below. It includes only the sequence for the logic that needed to be added for this project. As shown in the sequence a method of determining when the SRC could be utilized was required. This was accomplished with the solar system status signal which turns on when the solar heating system is running and has enough heat to be useful in the SRC, supply temperature greater than 80 degrees Fahrenheit. The sequence shows that the program gives priority to the SRC when solar heat is available and only uses the electric heater if there is no solar energy available or if the SRC cannot carry the entire heating load. The last part of the AHU controller sequence deals with the two new sensors, and shows that the program simply needed to display and record these values.

AHU Controller (ALC)

- AHU shall maintain current operation when solar system status input is not on.
- When solar system status input is on, heating will be done by the solar heating coil.
- Heat supplied by the solar heating coil will be modulated by a fluid bypass valve which will be controlled to maintain the current heating temperature set point.
- If the solar system status input is on and the solar heating coil is being fully utilized (bypass < 5%) and more heating is required the electric heater will be utilized to backup the solar heating coil.
- AHU controller will receive and record values from the new SRC LAT sensor and SRC flow meter.

The sequence of operations for the solar heating system controller is shown below. It shows only the sequence for the logic that needed to be added. There were only two modifications to the control code for the solar heating system. First, the controller needed to send the solar system status signal when the solar heating system is running and that the return temperature from the panels, supply to the SRC, was above 80°F. The second addition was a speed control for the pump. Previously the pump always operated at 50% speed; however, for this project a supply temperature of 100°F or above was desired.

Solar Heating System Controller (KMC)

- The solar system shall maintain current operation with two modifications.

1. When the solar system is running (pump on) and the glycol returning from the panels is above 80 degrees Fahrenheit the solar system status signal shall be sent to the ALC system.

2. The pump speed shall be controlled to maintain a constant supply temperature of 100 degrees Fahrenheit to the solar heating coil; however, the speed will not be allowed to fall below 40% or exceed 65% of full speed.

The temperature control is accomplished by allowing the pump to fall to as low as 40% speed when the temperature returned from the panels was below 100°F, which results in more dwell time in the panels and higher temperatures. When the temperature goes above 100°F, the pump speeds up to reduce the dwell time and will try to keep the return temperature from the panels at 100°F, this also allows for higher flow rates in the SRC and a higher heat transfer capacity.

Communications

The next issue in the controls design was the lack of communication between the solar heating system and the AHU. Prior to this project, the controls for the AHU and the solar system were completely separate with no means of communication. As such, one of the portions of the controls design was implementing a method to enable communication between these two control systems so that the AHU would know when solar heat was available for use in the SRC.

Figure 10.3.1 illustrates the additional control points added to the system as well as the added communication between the two controllers. An analog signal named "solar system status" is being used to communicate the status of the solar system to the AHU controller. The "solar system status" output from the solar system controller turns on when the solar heating system is running and the temperature returning from the panels is greater than 80 degrees Fahrenheit. This was discussed in more detail in the sequence of operations section of the controls design.

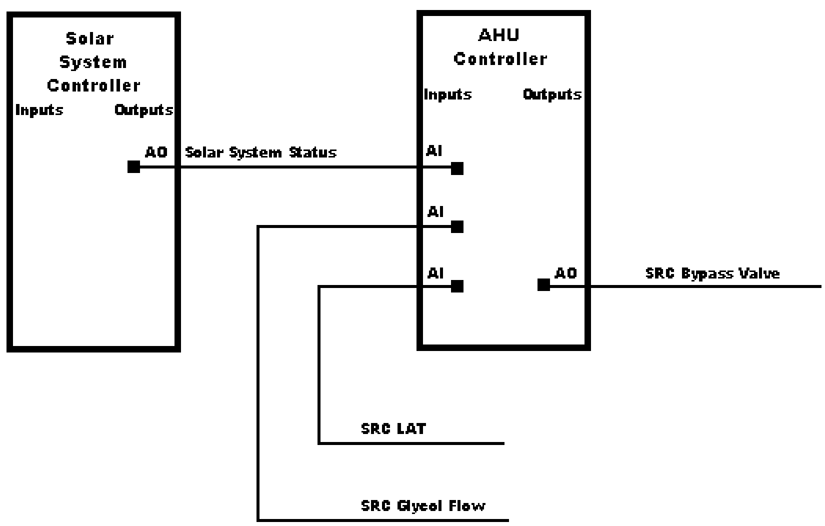

Figure 10.3.1. Controls Wiring Added for SRC

Hardware and Wiring

This project required the addition of a point expander module so that the controller for the AHU could receive additional inputs. While there were enough spares for the added output on the current controller, there were no spare inputs to the AHU controller before the onset of this project. Fortunately, there was an expander already in the lab that had not yet been installed. Figure 10.3.2 shows a picture of the expander module that was installed. This expander module had room for four additional inputs, of which three were required leaving on spare for future expansion of the system.

Figure 10.3.2. ALC Expander Module

Additionally, an analog output was added to control a solenoid actuated three-way valve. The valve was installed to act as a coil bypass valve which controls the amount of heated water/glycol mixture that enters the heating coil. As stated in the mechanical design, the SRC needs to be bypassed when heating is not required to maintain system flow; this operation requirement is the reason a two-way valve could not be used as in most hot water heating coils.

Two analog inputs were added to the system purely for data collection purposes. First, an average air temperature sensor was added to the AHU right after the SRC. This sensor measures the SRC LAT which can be used in combination with the cooling coil LAT sensor to determine the temperature rise across the SRC. The second sensor that was added was a flow meter. This meter was added to measure the amount of heated fluid that enters the SRC. As mentioned, since this coil operates with a bypass, the total flow of the system cannot be used to determine the flow through the coil and a dedicated flow meter was required.

Software Controls

The last step of the controls design was writing the actual code that would be loaded into the controllers. With the sequence of operations finalized, the control code for both systems was written to match. The program for the AHU was written in Eikon and uploaded to the ALC controller. The program for the solar heating system controller was written in WinControl and uploaded to the KMC controller.

10.4. Test Protocol

The test protocol was defined to ensure consistency throughout the testing of this project. The test occurred in two parts: one set of tests without the SRC and one set with the SRC. In the test protocol, the parameters that need to be consistent between all tests (without the SRC, baseline tests, and with the SRC, experimental tests) were defined first. Once all of the parameters that would remain the same were defined, a description of the unique parameters for each set of tests was completed.

10.4.1. General Test Protocol

The first variable to be defined was the amount of testing required. It was decided that for both the baseline and experimental tests that a minimum of seven days of data needed to be recorded. During the tests more data was actually collected for the experimental tests to ensure that the operation of the SRC could be more accurately described.

The schedule that would be used for the tests was one of the common parameters that needed to be defined. It was decided that each test would consist of a single day, 24 hours of run time, and data collection. These tests began at 12:00 a.m. of the test day and ran until 12:00 a.m. the following day. In the case that a test was not run on the previous day, then a two hour warm up period was scheduled, starting at 10 p.m. the previous day, to allow the system to reach steady operation before the test began.

The set points that would be used for the AHU needed to be defined in order to ensure consistency between tests as well as possible future work. First, the RAT was controlled to the heating and cooling temperature set points of 70°F and 72°F, respectively. The RA humidity was controlled to the humidification and dehumidification set points of 35% and 55%, respectively. The ERV was on. The OA damper was set to a constant 30% open, with the RA damper set to a constant 70% open. The fan differential pressure was set to 0.25 inches of water.

In both sets of tests a simulated cooling load was used in the zone. Since the conditioned zone is an interior space, the AEL's hydronic bench had to be used to introduce a cooling load into the zone. The goal was to maintain a roughly 1kW cooling load on the zone. This was accomplished by locking the hydronic bench valves to only allow heated water from the boiler into the loop. Then the boiler temperature was set to 80°F for each loop.

10.4.2. Baseline Tests

As mentioned above, the baseline tests were run without any modifications to the AHU, which is described in the introduction section of this paper. During the baseline tests the AHU and hydronic bench operated as described above in the general test protocol. In total, seven baseline test days were run between July 11, 2009 and July 20, 2009.

10.4.3. Experimental Tests

The experimental tests were run after the modifications mentioned in both the mechanical design and controls design sections were completed. In these tests additional constraints had to be placed on the operation of the system as equipment that was not used in the baseline tests was now in place. As mentioned in the controls design section, the SRC was given priority over the electric reheat coil. The solar system pump was modulated from a minimum of 40% speed to a maximum of 65% to attempt to maintain a 100°F supply temperature to the SRC. Lastly, the pump turned on only when there was enough solar energy to allow the PV array to recharge the batteries that powered the pump to the reconnect voltage of 53.5 volts. In total, 11 experimental test days were run between September 5, 2009 and September 22, 2009.

10.5. Data

For this project a standard method of data collection was created. It was decided that all data would be collected on one-minute intervals from the ALC system and on fifteen minute intervals from the KMC system. The reason for the larger time interval for the KMC system lies with the systems limited memory. If data had been collected on one-minute intervals the data would not be able to be stored for an entire day. It was also decided that since most of the data coming from the system was averaged over 15 minutes, like the solar intensity, or did not change rapidly, like the OA temperature and humidity, that more rapid sampling was not required for this data. All of the data collected was placed in an Excel file with two worksheets for each day, one for the ALC data and one for the KMC data.

For the two different sets of tests most of the data collected was the same; however, there was some additional data collected for the experimental test days. For all tests the outdoor conditions like temperature, humidity and solar intensity were recorded. The power and energy consumption of all of the system components along with the supply and return temperatures for the hydronic loop were recorded for all tests. Lastly, the values from all of the temperature, humidity and flow sensors in the AHU were recorded for all test days. The sensors can be seen in Figure 10.2.1. The values from the new sensors, as well as the value of the solar system status signal, were only recorded during the experimental tests as they were not present in the baseline tests.

The test data is summarized in Table 10.5.1. The left column is the date of the test. The second and third columns are the average outdoor temperature and outdoor relative humidity averaged over a 24-hour period. Column 4 is the total insolation over the course of a day measured in W-h/m^2. Column 5 is the maximum solar intensity recorded over the course of the test day. Column 6 is the average zone load that simulate transmission heat gains into the space. Columns 7 and 8 are the chiller energy and heater energy in kWh over the 24-hour duration of the test.

Table 10.5.1. Summary of Data Collected for Test Dates

	Average DB Temp	Average RH	Total Insolation	Max Solar Intensity	Average Zone Load	Chiller Energy	Heater Energy	Equip Issues	Dehumid Required	Valid Day
	(˚F)	(%)	(W-h/m^2)	(W/m^2)	(W)	(kWh)	(kWh)		% of Day	
7/11/2009	75.1	71.4	1499	363	904.6	63.36	44.86	No	100.0	Yes
7/12/2009	72.6	45.5	5415	797	869.5	54.83	40.85	No	99.9	Yes
7/14/2009	71.9	38.3	4572	799	781.3	38.12	4.27	Yes	47.6	No
7/15/2009	73.9	61.2	3197	695	886.1	55.40	34.54	Yes	90.8	No
7/16/2009	74.2	51.4	5632	867	937.9	56.01	40.50	No	100.0	Yes
7/17/2009	66.1	52.9	4123	747	871.3	46.15	31.18	No	86.9	Yes
7/19/2009	66.7	55.6	3555	618	622.3	34.39	0.09	No	20.6	No
9/5/2009	69.7	54.1	4066	874	970.9	50.22	23.91	No	99.5	Yes
9/6/2009	67.6	57.6	2421	532	965.1	49.19	28.86	No	99.6	Yes
9/7/2009	67.7	62.7	4743	876	948.2	49.23	25.41	No	99.7	Yes
9/9/2009	67.7	78.0	2685	797	942.2	51.01	31.47	No	99.7	Yes
9/10/2009	70.1	63.7	5752	948	956.8	52.52	24.19	No	99.7	Yes
9/15/2009	71.0	58.0	4564	814	967.6	52.35	22.30	No	99.2	Yes
9/16/2009	66.7	60.3	5846	960	968.3	48.69	21.57	No	99.6	Yes
9/18/2009	63.7	50.2	6801	1023	624.3	30.73	0.09	No	0.5	No
9/19/2009	65.3	52.8	5811	952	754.3	36.70	9.80	No	53.2	No
9/20/2009	63.6	63.2	1659	440	707.8	36.50	10.51	No	43.5	No
9/21/2009	69.9	72.4	1541	346	937.0	52.06	32.46	No	99.7	Yes

The last three columns were used to determine the validity of the tests. The column labeled "Equipment Issues" shows if there were any malfunctions with the equipment or sensors throughout the course of the test. If a malfunction occurred, then the test was considered invalid. The column labeled "Dehumid Required" shows the percentage of the day that the RA humidity was above 54%, which meant that the system was dehumidifying. 54% was chosen as it is the lower limit of the natural cycling of the humidity when the system was dehumidifying. The last column, labeled "Valid Day", simply looks at whether there were no equipment issues and if dehumidification was required for at least 75% of the day. Since the SRC only works when dehumidification is required, a day with less than 75% of the day requiring dehumidification and reheat was not considered to have enough data with the system operating to be useful in the analysis.

The last thing that Table 10.5.1 shows are the two days that were considered similar days for purposes of comparison and analysis. Table 10.5.1 has these two days shaded. The baseline test day was July 17, 2009 and experimental test day was September 5, 2009. Unfortunately, it is difficult to claim two days are identical for this project. The selection of the two days was determined mostly by the similarity of the average temperature and total insolation with some attention paid to the proximity of the average relative humidity.

11. Results

Table 11.1 re-summarizes the data for the two similar days that were used as the basis for evaluation. The data for July 17 is representative of a baseline test day without the SRC. The data for September 5 is representative of an experimental test day with the SRC in use. As mentioned earlier, it was determined that July 17, 2009 and September 5, 2009 had similar outdoor conditions, primarily temperature, insolation and humidity. Graphs of temperature, relative humidity and solar intensity over the course of both days can be found in Appendix 15.2.

Table 11.1. Summary of Data for Similar Days

	Average DB Temp	Average RH	Total Insolation	Max Solar Intensity	Average Zone Load	Chiller Energy	Heater Energy	Equip Issues	Dehumid Required	Valid Day
	(˚F)	(%)	(W-h/m^2)	(W/m^2)	(W)	(kWh)	(kWh)		% of Day	
7/17/2009	66.1	52.9	4123	747	871.3	46.15	31.18	No	86.9	Yes
9/5/2009	69.7	54.1	4066	874	970.9	50.22	23.91	No	99.5	Yes

Table 11.1 shows that the chiller energy use for both days was similar. However, the baseline test (July 17, 2009) did have slightly less chiller energy use. There were two reasons for the difference. First the average load in the zone was lower on the baseline test day. This resulted in less cooling required to cool the zone. Second, the percentage of the day that dehumidification was required was lower for the baseline test. This resulted in a lower latent cooling load for dehumidification. Each of the differences resulted in about one half of the discrepancy.

Table 11.1 shows a reduction in heater energy when the SRC was used. Since the baseline test day used less chiller energy, it should have also used slightly less heater energy. However, as Table 11.1 shows, the experimental test day (September 5, 2009) actually used roughly 25% less heater energy over a 24 hour period. This shows that as expected the SRC had the desired effect of supplementing the electric heating coil.

The remainder of this results section will compare and contrast the energy performances on the two similar days. The results will be presented in pairs of graphs. Each pair will have one graph for July 17, 2009 and one for September 5, 2009. This will allow for an easier comparison of the two days and illustration of the impact of the SRC.

Figures 11.1 and 11.2 show the energy consumption by component for both of the similar days over the full 24 hour tests. Figure 11.1 shows the energy consumption for the baseline test day when the SRC was not used. Figure 11.2 shows the energy consumption for the experimental test day when the SRC was used. The energy consumption is shown as a percentage of the total energy consumption of the system. Both figures show the relative energy consumption for the fan, chiller, ERV, heater and humidifier; however, Figure 11.2 also includes the energy consumption of the pump from the solar heating system. The pump was not included in the test without the SRC because the AHU was not receiving heat from the solar heating system in these tests.

Figures 11.1 and 11.2 show the relative amount of energy consumed by the electric heater was lower for the experimental test (Figure 11.2) than it was for the baseline test (Figure 11.1). Figure 11.1 shows that the electric heater consumed 34% of the energy when the SRC was not used. Figure 11.2 shows that the energy consumed by the electric heater was only 27% of the total energy consumed when the SRC was used.

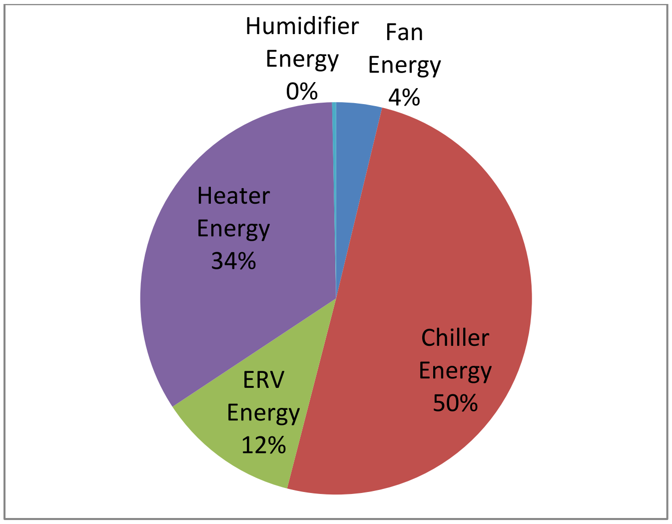

Figure 11.1. Relative Energy Consumption by Component for July 17, 2009 over 24 hours

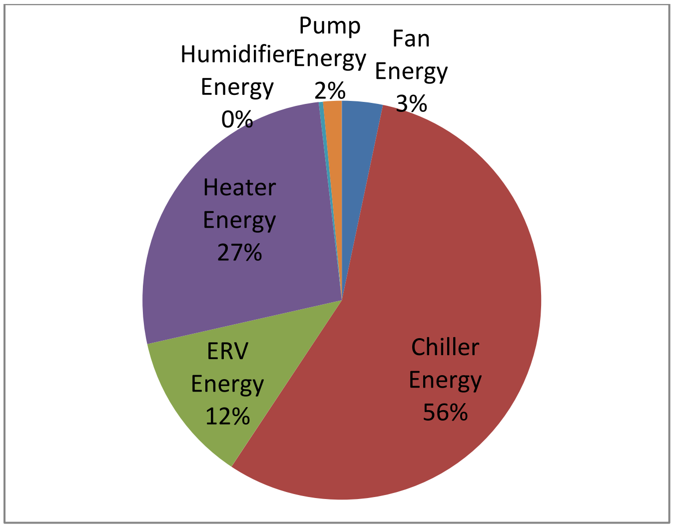

Figure 11.2. Relative Energy Consumption by Component for September 5, 2009 over 24 hours

Figures 11.3 and 11.4 show the relative energy consumption by component for both of the similar days over a 12-hour period. The SRC only supplemented the electric heating coil when solar energy was available. As such, a 12-hour period during the day was used to better illustrate the affects of the SRC on the relative energy consumption of the components. The 12-hour period used for Figures 11.3 and 11.4 was from 8 a.m. to 8 p.m.

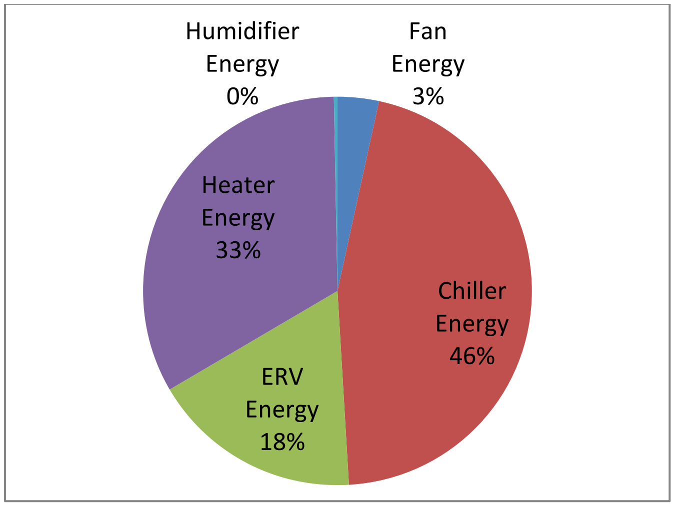

Figure 11.3. Relative Energy Consumption by Component for July 17, 2009 over 12 hours

Figure 11.3 shows the energy consumption for the 12-hour period on the baseline test day when the SRC was not used. Figure 11.4 shows the energy consumption over the 12-hour period for the experimental test day when the SRC was used. The energy consumption is shown as a percentage of the total energy consumption of the system. Both figures show the relative energy consumption for the fan, chiller, ERV, heater and humidifier; however, Figure 11.4 also includes the energy consumption of the pump from the solar heating system. Once again, the pump was not included in the test without the SRC because the AHU was not receiving heat from the solar heating system in these tests.

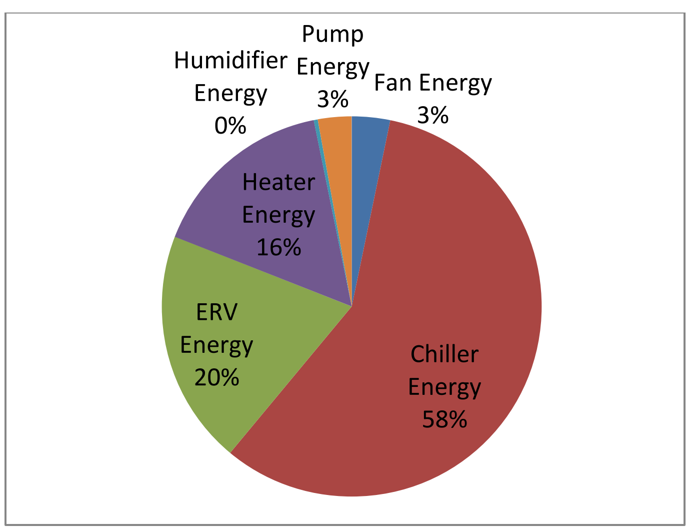

Figure 11.4. Relative Energy Consumption by Component for September 5, 2009 over 12 hours

Figures 11.3 and 11.4 show that the heater energy was reduced through the use of the SRC. Figure 11.3 shows a heater energy usage of 33% of the total when the SRC was not used. Figure 11.3 shows that the heater energy usage dropped to only 16% of the total energy use when the SRC was operating. The additional pump energy also needs to be taken into account; however, the pump consumed only 3% of the overall energy, which is much less than the heater energy saved.

Figures 11.5 and 11.6 show energy consumption by component over the course of the two similar days. Figure 11.5 shows the energy consumption by component for the baseline test day. Figure 11.6 shows the energy consumption by component for the experimental test day. Values of energy are in the units of kWh. In Figures 11.5 and 11.6 the slope of the line indicates the rate of energy consumption. A positive slope indicated energy consumption with a slope of zero indicating no energy use.

Figures 11.5 and 11.6 show that the energy consumption over the course of a day is fairly stable. As, such the graphs in figures 11.5 and 11.6 are fairly linear with two exceptions. First, the heater energy graph in Figure 11.6 starts out increasing linearly, then levels off during the day and resumes its linear increase in the evening. The section of the graph that levels off is circled in Figure 11.6. This indicates that the electric heater used much less energy during the day when compared to its nighttime usage. This decrease in the rate of consumption shows that the SRC was supplementing the electric heater.

The heater energy graph in Figure 11.5 levels off toward the end of the test. The circle on Figure 11.5 indicates the section of the heater energy graph that leveled off during the baseline test day. The reason that the heater stopped consuming energy was the outdoor humidity decreased. This resulted in no dehumidification, and therefore, not reheat being required at the end of the test. The decrease in outdoor air relative humidity can be seen in the graphs of outdoor conditions in Appendix 15.2.

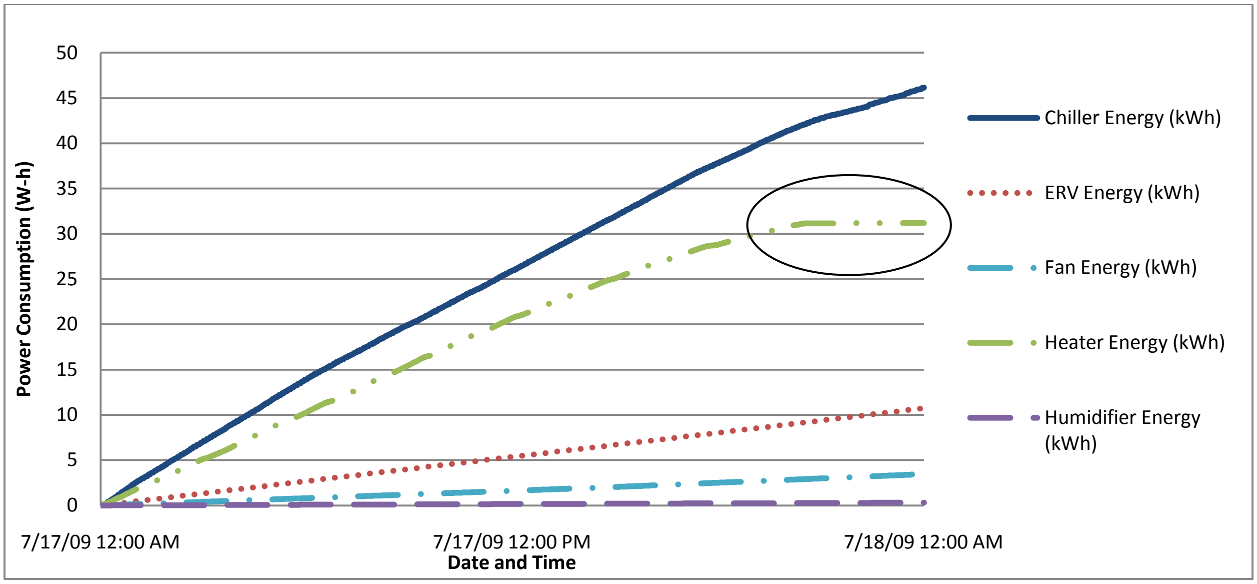

Figure 11.5. Energy Consumption by Component for July 17, 2009

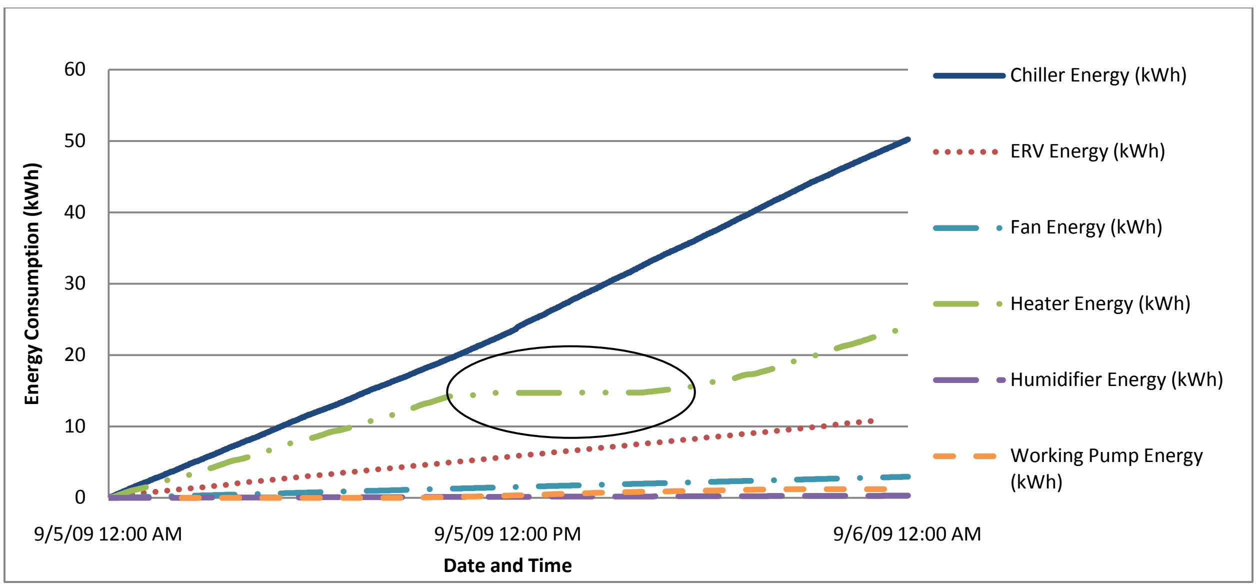

Figure 11.6. Energy Consumption by Component for September 5, 2009

The main focus of this project was to reduce the heater energy. As such, the next graphs will focus in on performance of the heater over the course of the two similar test days. First, a method of approximating the energy required for reheat will be discussed. Next, will be a comparison of the actual energy consumed by the heater and the approximated energy required. Last, will be the conclusions that were reached about the performance of the SRC.

Figure 11.7 develops a technique for estimating heater energy use. The graph shows both the power and energy consumption of the electric heater over the course of the baseline test day of July 11, 2009. July 11, 2009 was used for this section because dehumidification and reheat were required all day, as seen in Table 10.5.1. All day dehumidification and reheat was desired for this section simply for the ease of explanation. In the figures the dashed line represents the energy consumed, read from the left vertical axis in kWh. The solid line represents the power consumption of the electric heater, read from the right vertical axis in kW. The power to the electric heater is staged, not infinitely modulated, which causes the variation in the heater power shown in Figure 11.7. Lastly the R^2 value is the correlation coefficient, which compares the actual heater energy line to a best fit linear trend line.

Using Figure 11.7, an approximation of heater energy required can be made. Since the plot of heater energy is fairly linear (R^2 of 0.9999), it was assumed that while dehumidification was required that the energy require for reheat would increase linearly. As such, for each baseline test day the average rate of electric heater energy use was calculated when dehumidification was required. This value was used to determine the heater energy required throughout the day, which will be discussed in further detail later. However, this method needed to be modified for the experimental test days. Only the electric heater energy use when dehumidification was required and when SRC was not in use could be used to determine the average because, when the SRC was in use, it should decrease the electric heater energy required.

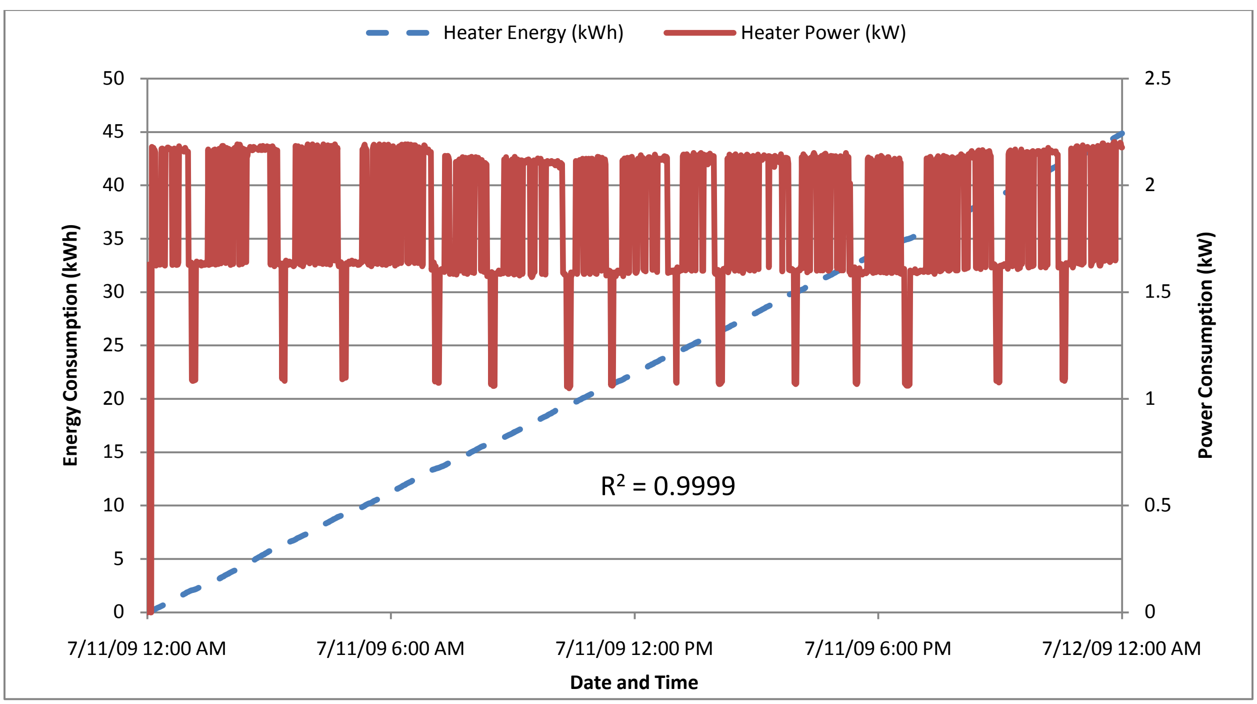

Figure 11.7. Electric Heater Power and Energy Consumption, July 11, 2009 (Baseline Test)

Figures 11.8 and 11.9 show the energy consumption of only the heater along with an approximation of the total reheat required. In Figures 11.8 and 11.9 the dashed line is the actual energy consumed by the electric heater in kWh. The solid line shows the approximated heater energy required as developed in Figure 11.7, also in kWh.

Figure 11.8 shows the validity of using the method discussed above to approximate the heater energy required. For the baseline test days these two lines should line up directly on top of each other; however, as Figure 11.8 shows, they do not. They are, however, very close and as Figure 11.8 shows, the approximation also follows the actual when dehumidification and reheat where not required in the evening.

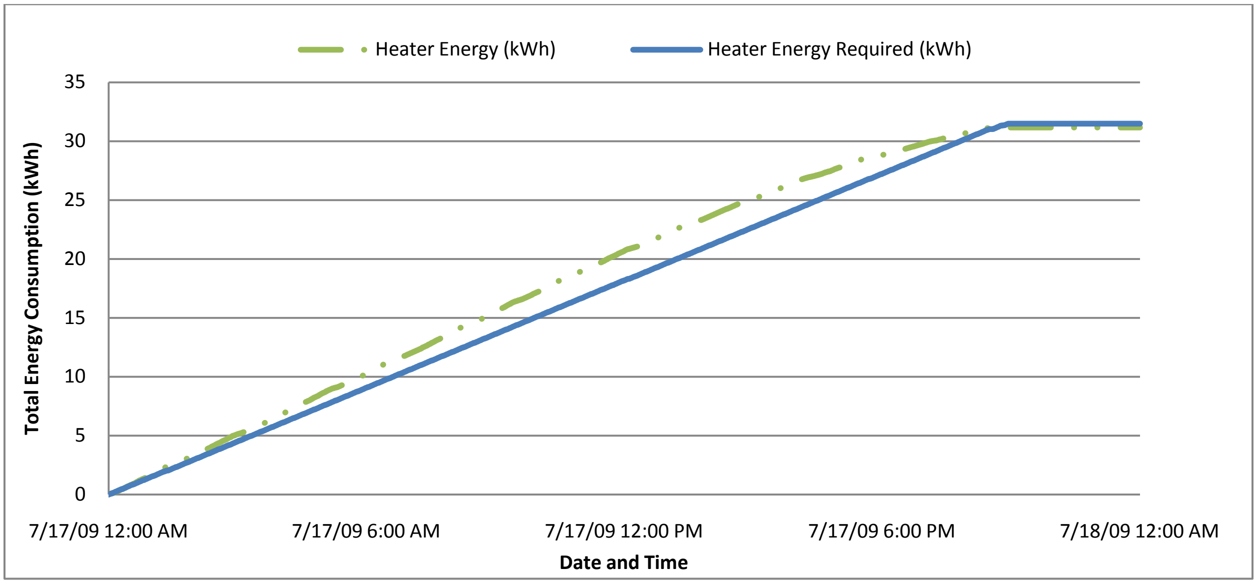

Figure 11.8. Baseline Test Assumed Heater Energy Required and Electric Reheat Energy Consumption

Figure 11.9 shows the affects of the SRC on the electric heater energy use. Table 11.1 shows that for September 5, 2009 dehumidification, and therefore, reheat were required 99.5% of the day. This high percentage of dehumidification and reheat results in a heater energy required graph that steadily increased over the entire day. However, as Figure 11.9 shows the electric reheat coil did not use much energy during the day as shown by the section of the heater energy graph that leveled off. The difference between the electric heater energy and the heater energy required is the input of the SRC shown in Figure 11.9 as “Energy Savings”. As such, Figure 11.9 shows that for September 5, 2009 the SRC saved almost 10 kWh of electricity.

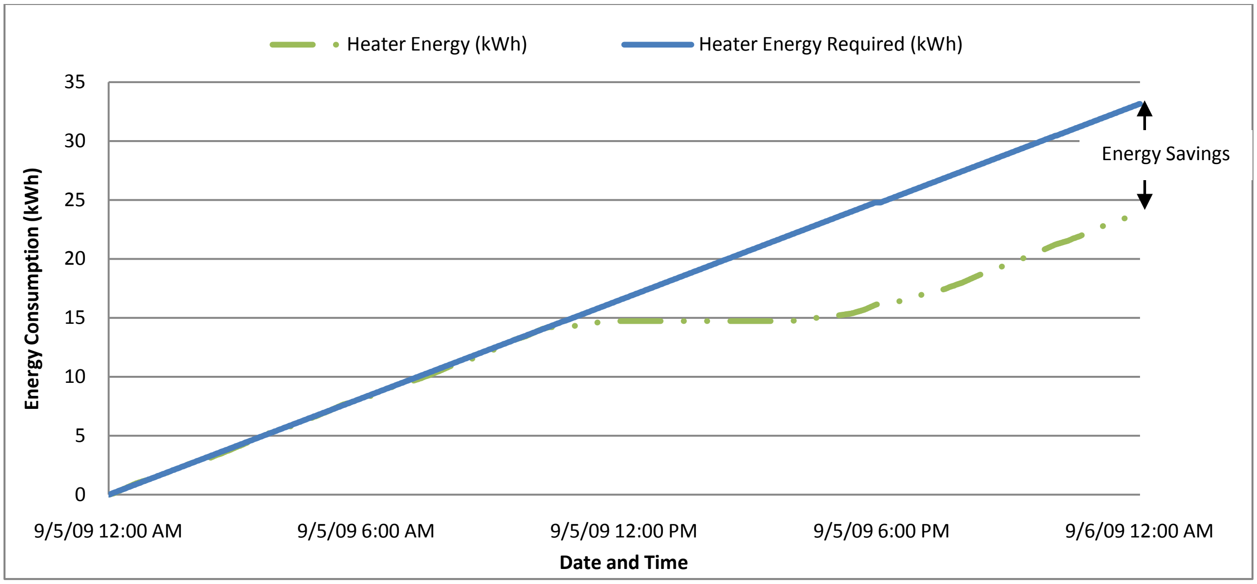

Figure 11.9. Experimental Test Assumed Heater Energy Required and Electric Reheat Energy Consumption

The results have shown that the SRC has successfully supplemented the electric reheat coil. The main indicators of the energy reduction are summarized in the bullets below:

- Figures 11.3 and 11.4 show that energy consumption of the electric heater relative to the total energy consumed fell from 33% to 16% with the use of the SRC over a 12-hour period.
- Figure 11.9 shows that for September 5, 2009 the solar reheat coil saved almost 10 kWh, over 25% of the energy required for 24-hour operation.

12. Future Work

Through the process of completing this project it became apparent that a few improvements should be made to the system. While the system is functional, there are a couple of alterations that could improve the overall performance and reliability of the system. First, a three way control valve should be added to modulate the flow from the SRC to the older plate and frame heat exchanger for heat rejection. Second, the controls for the AHU could use a few efficiency updates.

12.1. Control Valve Addition

Currently, the solar heating system is manually switched from the old plate and frame heat exchanger to the SRC manually. The heated fluid cannot flow to the SRC at all times because the SRC is not used at all times. If left connected to the SRC, the temperature of the heated fluid will drift substantially. This temperature drift could cause the heat pipes in the heat pipe collector to over pressurize and break their seals, which would cause the heat pipe to no longer function.

A three-way valve should be added to modulate the flow between the SRC and the older heat exchanger to reduce the risk of overheating the panels. Figure 12.1.1 shows the where the three way valve should be placed. The location is in the dashed box where a tee is currently located. The tee should be removed and replaced with a solenoid actuated three-way valve. The quick connect that the solar system is hooked to should remain.

Figure 12.1.1. Suggested Location of Control Valve

The new valve should be controlled by the KMC controller for the solar heating system. The new valve should remain open to the SRC until the temperature returning from the roof is high enough to be considered harmful to the panels. Once the temperature has reached this point, the three-way valve should begin to modulate to reduce the temperature. The control should not allow the valve to go full open quickly. The control needs to operate slowly because the fluid that is cooled in the old plate and frame heat exchanger will not recirculate back to the return temperature sensor quickly due to the large volume in the system and low flow rate. If the control operates too quickly, the system will cycle from one extreme to the other instead of controlling the temperature as desired.

12.2. AHU Logic Updates

The AHU does not operate as efficiently as it should at all times. First, the current AHU controls do not include code for an economizer. Second, the controls have a strict humidification set point which is set for summer humidification. This high humidification set point results in excessive humidification on dry winter days. Resolving these two issues would allow the AHU to operate more efficiently.

Code for an economizer should be written for the AHU. The economizer should reduce the energy required for cooling in the AHU. The new control should allow the OA damper to adjust to maintain a MAT that is equal to the DAT. The economizer should not be used whenever the temperature outside is greater than the RAT or if the dew point outside is greater than 55 ˚F. The economizer code should also not allow less than minimum OA to be taken in, which needs to be determined for the space and may change depending on the type of space that is being approximated by the environmental chamber.

The humidification control set points should be modified to track with outdoor air temperature. Currently humidification occurs whenever the return RH falls below 30%. This leads to constant humidification on dry winter days. However, allowing the humidification set point to decrease as the OAT decreases would save humidifier energy. ASHRAE standard 62.1 should be referenced for the humidification reset set points.

13. Conclusion

The completion of this project has resulted in a working prototype for solar powered reheat. With a few modifications as mentioned above, this system will prove useful in future research. With solar assisted reheat being one of only a few acceptable forms of reheat for ASHRAE 90.1 (2007), interest in this topic will continue to grow and further research will be necessary. Therefore, this project has put Purdue University and the AEL in a position to be a frontrunner in the up and coming field of solar assisted reheat research.

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15. Appendix

15.1. Trane Coil Specs

Heating coil

Job Information

Name	**Job01**	Tag	
Address		Quantity	
Sales Team		Model Number	**DP4B18015F0BA080 BA-A00A**
Comments			

Design Options

Casing option	**Galvanized**	System type	**Hot Water**
Apply ARI ranges	**No**	Coil utilization	**Shipping coil**
Elevation	**0.00 ft**	Fouling factor	**0.00050 hr-sq ft-deg F/Btu**

General

Solution number	**1.00 Each**	Actual coil face area	**1.88 sq ft**
Face velocity	**347 ft/min**	APD	**0.06 in H2O**
Rigging weight	**30.6 lb**	Installed weight	**35.3 lb**
ARI 410-01 classification	**Outside scope**	Actual airflow	**650 cfm**
Airflow and connection side	**RH supply**	Coil application	**Heating coil**
Entering dry bulb	**50.00 F**	Entering fluid temp	**100.00 F**
Standard fluid flow rate	**1.37 gpm**	Fluid temp drop	**12.20 F**
Leaving dry bulb	**60.23 F**	Total capacity	**7208.25 Btuh**
Coil type	**P4**	Rows	**2**
Coil tube drainability	**Drainable**	Fin spacing	**80 fins per foot**
Fin material	**Aluminum**	Fin type	**Prima-Flo E**
Tube matl/wall thickness	**.020 (0.508 mm) copper**	Fluid type	**Propylene Glycol-No ARI Cert.**
Fluid concentration	**50.00 %**	Nominal coil height	**18" (457 mm)**
Finned length	**15" (381 mm)**		

Steam Coil

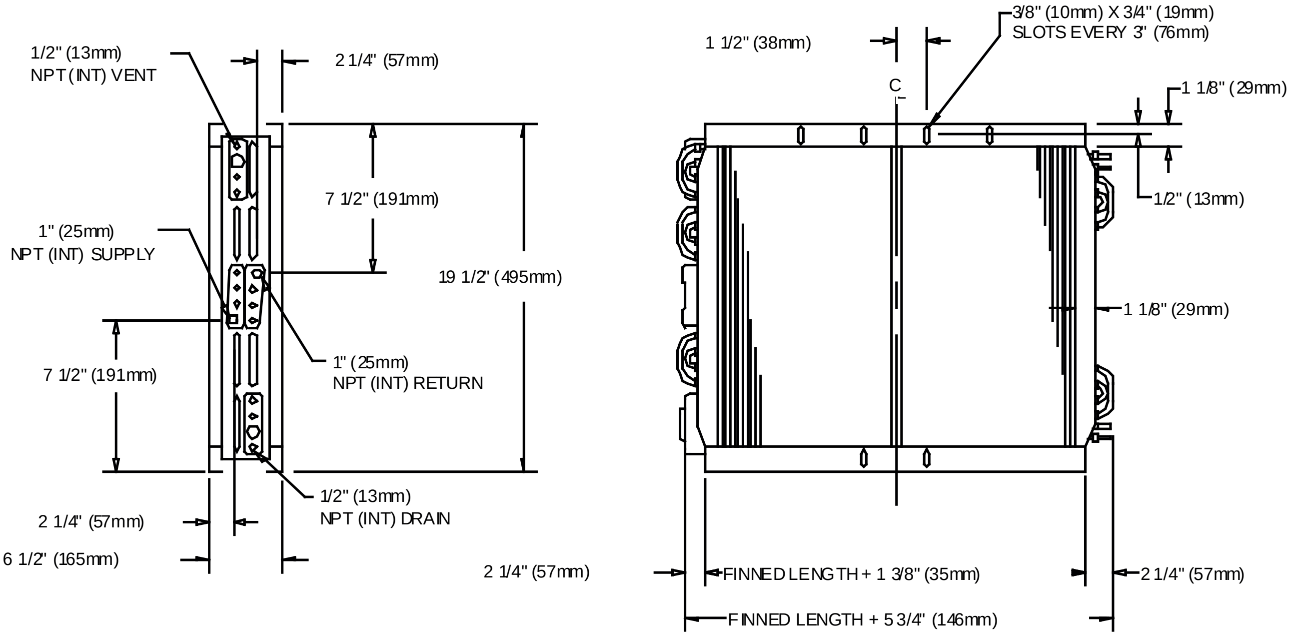
Casing option	**Galvanized**

Hot Water Coil

Casing option	**Galvanized**	Leaving fluid temp	**87.80 F**
Fluid PD	**0.10 ft H2O**	Fluid velocity	**0.38 ft/sec**
Volume	**0.56 gal**	Reynolds number	**529.33 Each**

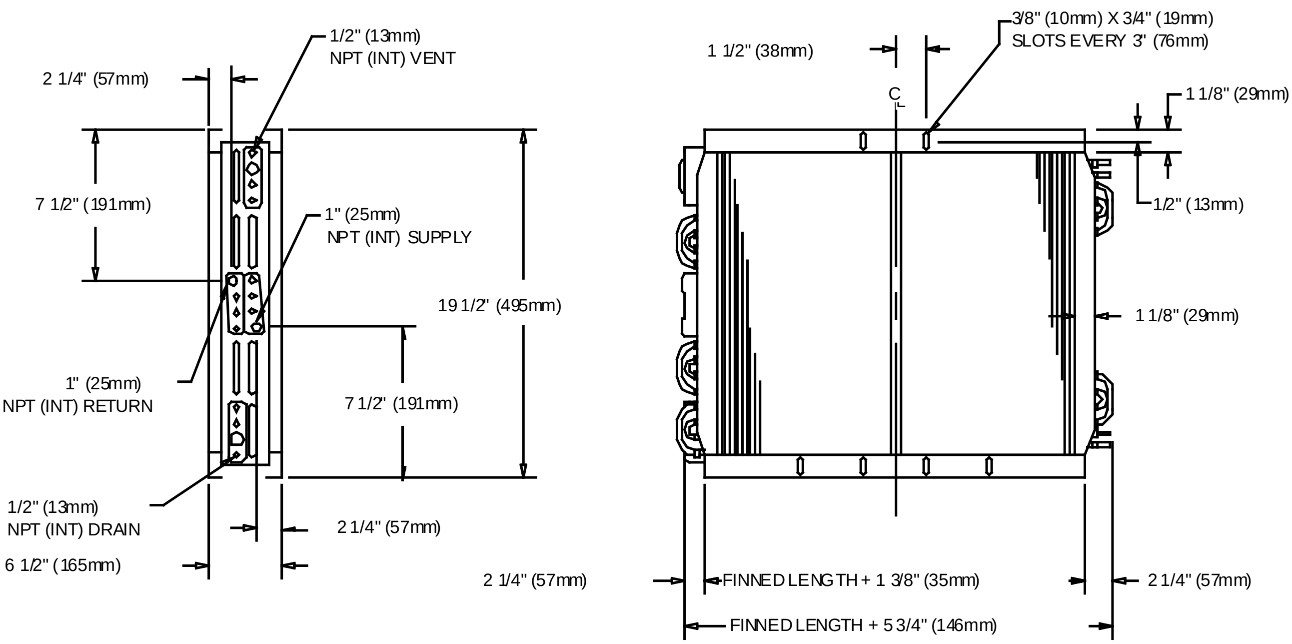
Coil Bank

Casing option	**Galvanized**



AIR FLOW

RIGHT HAND



LEFT HAND

AIR FLOW

GENERAL
Coil is manufactured by Trane. Coil will be designed with aluminum or copper plate fins and copper/copper alloy tubes. Fins have collars drawn, belled and firmly bonded to the tubes by means of mechanical expansion of the tubes. Coil has airflow arrow and nameplate attached to coil casing.

COIL CASING
Coil casing is manufactured with galvanized steel.

COIL PLATE FIN TYPE
Aluminum plate fin is Trane PRIMA FLO E (Energy Efficient) fin design.

COIL SUPPLY CONNECTION
Coil supply connection is on right side of coil with horizontal airflow (facing airflow).

15.2 Weather Data for Similar Test days